Straw Recovery as Affected by Wheat Harvest Method

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ABSTRACT

DECLINING petroleum reserves have brought attention to crop dry matter as a potential source of energy for the future. Wheat dry matter yield and the portions potentially recoverable for energy conversion by different harvesting methods were investigated at Bushland, TX, from 1979 through 1983. Wheat was managed with varying amounts of irrigation to achieve both medium and high dry matter production levels. Where all dry matter was removed by hand and threshed, the grain, straw, and chaff fractions averaged about 40, 50, and 10%, respectively, of the total material. When clipping samples at a simulated combine harvesting height (about 36 cm), the remaining stubble amounts ranged from 1,700 to 3,400 kg/ha for grain yield levels of 3,400 to 6,700 kg/ha.

When the stubble was swathed and baled after conventional combine harvesting, baled straw weights ranged from 1,900 to 2,400 kg/ha (15 to 17% of total dry matter). Up to 3,700 kg/ha of stubble remained for erosion protection after swathing and baling. Where the combine cutter-bar was operated near ground level (5 to 7 cm) and all straw discharge was caught (whole plant combining), catchings ranged from 4,600 to 6,000 kg/ha, or 2.5 times greater than with conventional combining and baling.

INTRODUCTION

Petroleum shortages during the 1970s resulted in increased costs of fossil fuel for energy and caused the United States to focus on present and future energy sources. Plant dry matter has been among the renewable energy sources considered as a potential alternative to fossil fuels. Crop residues remaining after harvest are a major form of our nation's biomass. Pimental et al. (1981) estimated that 22% of crop and forestry residue might be used as a renewable energy source. They recognized that high costs to collect, transport, and process the material would limit net energy benefits. Larson (1979) estimated that about 16 million t, or 21% of the crop residue on the Great Plains, could be used for energy production; and the remainder would provide wind and water erosion protection. Wheat and corn residue account for about 85% of this amount. On some of the drier portions of the Western Plains, there is no residue in excess of that needed for erosion protection.

When estimates have been made as to quantities of crop dry matter available for energy sources, losses from gathering and transporting residue by machine have not usually been considered. Richey and Liljedahl (1980) investigated the salvage and handling of corn stover in Indiana and found that only about 2/3 of the stover could be gathered into a windrow for baling. Furthermore, they recovered only about 1/2 of the windrowed material when gathering with a big-roll baler or with a stackwagon. Thus, only about 1/3 of the stover was recovered by machine. Miller (1980) reported that the theoretical cost to bale straw and deliver it 40 km was $25 to $40 per t in California. A biomass production and use plan by USDA and USDOE (1983) projected that 45 to 75 billion L (12 to 20 billion gal) of alcohol could be produced annually if all agricultural residue were converted to alcohol regardless of cost. It was recognized in the plan that it would be difficult to economically collect and convert residue feedstocks to alcohol. Stout (1987) suggested that with current overproduction of farm commodities new uses for crop dry matter, such as industrial feedstocks, could be considered as an income alternative.

Concern about wheat residue as an energy source led to this investigation as to what portions of wheat residue could readily be recovered. The objectives were to determine the amounts of wheat dry matter produced under varying yield levels and the amounts recoverable by different harvesting and gathering methods.

PROCEDURE

The study included both hand and machine harvesting wheat of different plant heights and yield levels. Both short- and medium-statured wheat varieties were grown to provide differences in plant height. The yield levels were controlled by the amount of irrigation water applied. Hand harvesting was used to determine total above-ground dry matter yield. Grain and straw yields were determined by threshing the samples. Machine harvesting was used to determine the portion of dry matter yield recoverable by different machine gathering methods.

Hand Harvesting

In 1979, TAM 101, a short wheat, was sampled. In 1980, both TAM 105 (short) and Scout 66 (medium) were sampled. Sample areas were 1 x 3 m with four replications. Samples were clipped at ground level and at simulated combine cutter-bar heights. Total dry matter, grain, and straw fraction, plus the remaining stubble

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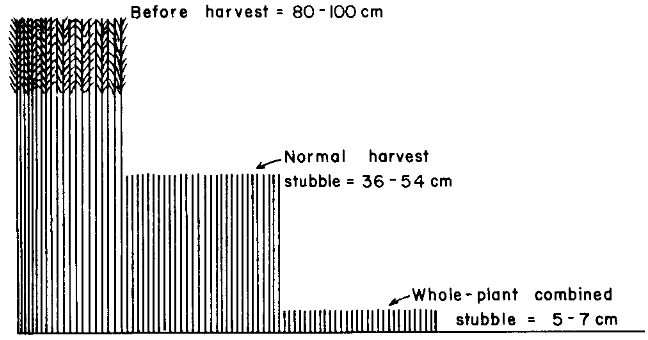

Fig. 1—Typical heights of wheat before harvest and stubble after both normal and whole-plant combining.

TABLE 1. WHEAT DRY MATTER WITH GRAIN AND STRAW FRACTIONS GATHERED BY HAND CLIPPING, BUSHLAND, TX, 1979-1980

Wheat variety	Plant height	Stubble height	Dry matter	Grain	Straw	Stubble remain
	cm		kg/ha			
1979						
TAM 101 (md) §	73	2*	8720	3700 (42)†	4400 (50)	
		25‡	8720	3700 (42)	3180 (36)	1220 (14)
TAM 101 (hi) §	76	2	18460	7400 (40)	9930 (54)	
		25	18460	7400 (40)	7160 (39)	2780 (15)
1980						
Scout 66 (md)	99	2	8400	3440 (41)	4580 (55)	
		40	8400	3440 (41)	2860 (34)	1720 (21)
TAM 105 (hi)	89	2	13200	5400 (41)	6720 (51)	
		35	13200	5440 (41)	4700 (36)	2020 (15)

* Clipped ground level.
† Numbers enclosed in parentheses signify a percentage of the total dry matter
‡ Clipped at simulated combine harvest height
§ (md) = medium yield level; (hi) = high yield level

amounts, were determined on a dry weight basis. Threshing was done with a Chain* bundle thresher.

Machine Harvesting

Each year, the wheats were grown under medium and high irrigation levels to obtain different yields. They were combine harvested with the cutter bar operating near ground level and at conventional cutting heights. All straw discharge was caught when cutting near ground level. When cutting at conventional heights, the remaining stubble was swathed and baled. Typical heights of stubble after harvest are illustrated in Fig. 1.

When cutting at ground level and catching the straw discharge, a plot-size Chain SP-50 self-propelled combine with a 1.4-m header was used so that the discharge could be caught in a trailing basket carried by two people. Two passes were made for each sample in order to reduce the straw load on the separator. Cutting was at normal height for the first pass and near ground level for the second pass. Sample areas were 1.4 x 3.0 m with three replications. Combine discharge catchings were weighted and sampled for moisture and were adjusted to a dry weight basis.

For conventional harvesting, an Allis Chalmers "F" combine with a 4.3-m header was used. A 4.3-m wide New Holland swather and a wire-tie New Holland rectangular baler were used for swathing and baling. Sample areas were 4.3 x 183 m with three replications. Bales were weighed and straw yield weights were adjusted to a dry-weight basis after oven drying subsamples. Stubble heights were measured after combining and swathing.

Fuel-use for combining was measured with a Zemco microprocessor-controlled flow meter mounted in-line between the fuel pump and carburetor of the 4.8 L gasoline engine on the Allis Chalmers combine. A sensor attached to the drive axle provided travel distance measurement.

RESULTS AND DISCUSSION

Hand Harvesting

The data for hand-gathered wheat dry matter are presented in Table 1. Wheat plants were generally shorter in 1979 than in 1980, as evidence by TAM 101 in 1979 being 12 cm shorter than TAM 105 in 1980. The TAM wheats are expected to be about equal in height in a given year. The total crop dry matter and grain yields were higher in 1979 with shorter plants, which shows that taller plants do not necessarily produce higher yields. The height difference for similar wheats in separate years shows the effect of year-to-year climatic variables. Wheat plant tillering and straw density can vary between years and between varieties to affect dry matter yield.

The grain fractions for the different wheat varieties averaged near 40% of the above-ground dry matter each year. The straw fraction averaged 50 to 55% of the dry matter where the whole plant was clipped. This straw fraction was all potentially available for energy conversion if soil erosion protection was not considered. Some 35 to 40% of the dry matter was potentially available for energy conversion where the wheat was harvested at a conventional height and 15 to 20% of the dry matter remained as stubble for erosion protection.

The 7,400 kg/ha grain yield for TAM 101, fully irrigated for maximum production in 1979, was exceptionally high as was the total dry matter yield. If the harvesting was done by machine on field basis, the grain yield would be expected to be 5 to 10% less. Some 5 to 10% by weight of the "whole-plant" samples was not accounted for and was assumed to be largely chaff losses from threshing and was not expected to be recoverable.

Machine Harvesting

The data for machine-harvesting in 1981 to 83 are present in Table 2. In 1981, the Centurk plants averaged about 7 cm taller than did TAM 105. Plants were markedly shorter (12 to 15 cm) for the medium yielding treatments of both wheats when compared with higher-yield treatments. The shorter plants were largely the result of irrigation being withheld during the rapid stem elongation period before heading. With full irrigation, the taller Centurk produced 13% more dry matter than did TAM 105; however, TAM 105 produced 14% more grain. The grain fractions ranged from 38 to 49% of the total dry matter, with TAM 105 being higher than Centurk under both yield levels. Where the combine header cutter-bar was operated as close as possible to ground level and the straw discharge was caught, Centurk yielded 19% more straw than did TAM 105 in

*Mention of a trade name or product does not constitute a recommendation or endorsement by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

the high-yield treatment. This higher straw yield was a result of the greater total dry matter yield with Centurk. The machine-recovered straw yields were lower than the hand-gathered yields, partially because hand clipping permits recovering more of the plant.

Straw yields with conventional combining followed by swathing and baling averaged about 2,000 kg/ha less than with whole-plant combining and catching the discharge in 1981. The straw-yield difference was the result of the custom operator-controlled swather cutting about 5 cm higher than desired, plus chaff losses and windrow-pickup losses with the baler. Chaff and short straw particles settled to the ground where the swather could not reach them. The weights of straw gathered by conventional combining wheat, then swathing and baling (2,200 to 3,100 kg/ha) were similar to those of Richey and Liljedahl (1980) where corn stover was swathed and baled near Lafayette, IN.

In 1982, dry matter levels were 13 to 19% higher than in 1981; however, the grain fractions were less (26 to 39% grain in 1982 vs. 38 to 49% in 1981). This again shows that grain yield is not always proportional to the total dry matter. In 1982, Scout 66 produced about 10% more dry matter with full irrigation than did TAM 105, but TAM 105 produced 29% more grain. In 1982, baled straw yields were quite low (10 to 12% of total dry matter because of a relatively high, 12- to 15-cm, swather cutting height. Wet, sticky soil conditions created swather control problems. Up to 4,100 kg/ha of stubble 26% of total dry matter) remained after swathing and baling.

In 1983, dry matter and grain yields were about 25% greater with full irrigation. The grain fraction was about 35% for both yield levels. Nearly 50% of the total dry matter was recovered when cutting low and catching all discharge; however, only about 15% was recovered by swathing and baling. About 5,000 kg/ha of the heavy stubble (35 to 40% of total dry matter) remained after swathing and baling. Similarly, Dobie et al. (1982) reported that when rice was harvested at ground level in California and all straw was caught, about 20% more straw was recovered than with a normal harvest height (Fig. 1) followed by swathing and baling.

Three-Year Average

The 3-year average dry matter production was about 15,400 kg/ha for the high-yield level and about 12,000 kg/ha for the medium-yielded level. The taller wheat

TABLE 2. WHEAT DRY MATTER WITH GRAIN, STRAW DISCHARGE, AND BALE YIELD FRACTIONS FOR DIFFERENT HARVEST METHODS, BUSHLAND, TX

Wheat variety	Plant height	Stubble height	Dry matter	Grain	Straw discharge	Bales	Stubble remain
	---------- cm ----------		---------- kg/ha ----------				
1981							
TAM 105 (md) §	80	5-7*	11600	5040 (43)†	4370 (38)		
		35-38‡	11600	5040 (43)		2260 (20)	2110 (18)
TAM 105 (hi) §	93	5-7	13280	6530 (49)	5310 (40)		
		46-48	13280	6530 (49)		3080 (23)	2230 (17)
CENTURK 78 (md)	85	5-7	8960	3560 (40)	4610 (52)		
		46-48	8960	3560 (40)		2210 (25)	2410 (27)
CENTURK 78 (hi)	100	5-7	14980	5710 (38)	6310 (42)		
		53-55	14980	5710 (38)		3120 (21)	3180 (21)
1982							
TAM 105 (md)	84	5-7	15000	4970 (36)	4930 (35)		
		38-40	15000	4970 (36)		1570 (11)	2820 (20)
TAM 105 (hi)	94	5-7	15900	6250 (39)	5040 (32)		
		44-47	15900	6250 (39)		1570 (10)	4100 (26)
SCOUT 66 (md)	92	5-7	12900	3290 (26)	4760 (37)		
		45-48	12900	3290 (26)		1570 (12)	3560 (28)
SCOUT 66 (hi)	100	5-7	17470	4840 (28)	5820 (33)		
		51-54	17470	4840 (28)		1690 (10)	3830 (22)
1983							
SCOUT 66 (md)	94	5-7	12140	4170 (34)	5540 (46)		
		46-48	12140	4170 (34)		1900 (16)	4890 (40)
TAM 105 (hi)	92	5-7	15060	5240 (35)	7450 (49)		
		40-42	15060	5240 (35)		2300 (15)	5270 (35)
Mean							
TAM 105 (md)	82	5-7	12800	5000 (39)	4650 (36)		
		36-30	12800	5000 (39)		1915 (15)	2460 (19)
TAM 105 (hi)	93	5-7	14600	6000 (41)	5930 (41)		
		43-46	14600	6000 (41)		2320 (16)	3740 (26)
SCOUT-CENTURK (md)	90	5-7	11320	3670 (32)	4970 (44)		
		46-48	11320	3670 (32)		1890 (17)	3620 (32)
SCOUT-CENTURK (hi)	100	5-7	16220	5270 (32)	6060 (37)		
		52-54	16220	5270 (32)		2410 (15)	3510 (22)

* At lower cutting height, all straw discharge was caught
† Numbers enclosed in parentheses signify a percentage of the total dry matter
‡ At higher cutting height, stubble was swathed and baled
§ (md) = medium yield level; (hi) = high yield level

produced slightly higher average straw amounts under both yield levels; however, the short wheat produced higher grain yields. The higher grain yield with semidwarf wheats is a characteristic that results in a greater proportion of the dry matter being produced in the form of grain as compared to that with medium and tall wheats.

Straw discharge collections for whole-plant combining ranged from 37 to 44% of the total dry matter, and baled straw amounts averaged only 15 to 17% of the total dry matter. The stubble remaining after baling ranged from 2,400 to 3,700 kg/ha, or 19 to 32% of the total dry matter. Collecting all straw discharge from whole-plant combining provided up to 2.5 times more material than did swathing and baling.

When comparing the relative efficiencies of straw recovery by the different machine harvesting methods in this discussion, the recovered straw yield can be expressed as a percentage of the "material other than grain" (MOG). The MOG is not listed separately in Table 2, but it can easily be determined by subtracting the grain fraction from total dry matter. Conventional combining and swathing recovered only from 22 to 45% of the MOG, whereas whole-plant combining recovered from 55 to 70% of the MOG. The value of the extra straw recovered by combining the whole plant would be partially offset by the slower machine speed and the resulting higher combining cost. An alternative would be to develop a secondary cutter bar to follow immediately behind and below the combine header which could windrow the straw. Such a design should cause less interference with normal combine travel rates.

Potential Energy Value of Recovered Plant Residue

The purpose of this study was to determine the portions of wheat dry matter that could realistically be recovered for potential energy conversion and not to conduct a detailed energy balance of output versus input. However, one can make general comments about the potential energy value of the recovered plant material versus the fuel energy needed to gather the feedstock based on this study and other published work.

Small grain residue produces about 3 million kcal of heat per dry metric ton (Larson, 1979). About 55% of this heat can be recovered usefully during combustion (Pimentel et al., 1981). With about 2,000 kg/ha of straw being recovered by swathing and baling in this study, the energy value contained in the residue is about 3.3×10^6 kcal (0.8×10^6 joules) per hectare. This is equivalent to 460 L/ha of gasoline. The fuel energy requirements to operate the combine during the differing conditions in this study are presented in Table 3. The fuel requirements for conventional combining were 12 to 13 L/ha of gasoline. Whole-plant combining required up to 24% more fuel than did conventional. The fuel energy consumed to swath, bale, and transport the straw 16 km is estimated at an additional 26 L/ha of gasoline.

If the primary objective in growing the crop is to produce grain, then the recovered dry matter could have net energy value. However, if the wheat is grown primarily for energy feedstock, then the energy output versus input is about break-even (Allen et al., 1977). If irrigation is required to produce the crop, then energy inputs can become about twice the value of the energy potentially recoverable in this study.

TABLE 3. ENERGY USE FOR HARVESTING WHEAT AT DIFFERENT CUTTING HEIGHTS AND YIELD LEVELS. AC MODEL "F" COMBINE HARVESTER, 4.2-m HEADER, 4.8-L, 71-kW GASOLINE ENGINE, BUSHLAND, TX 1983

Wheat variety	Grain	Dry biomass	Gasoline fueld use: Normal cut*	Gasoline fueld use: Low cut†	Fuel increase‡
	kg/ha	kg/ha	L/ha	L/ha	%
TAM 105 (high yield)	5240	15060	13.2	16.5	24.5
SCOUT 66 (med. yield)	4170	12140	12.0	13.9	16.3
SCOUT 66 (low yield, dryland)	2020	5350	9.4	10.5	12.0

* Normal combining height
† Cut approximately 7 cm above ground
‡ Increased fuel use for lower cutting

SUMMARY AND CONCLUSIONS

Total wheat dry matter yields, as well as the proportions of grain and straw produced, can vary considerably between years. The taller wheats generally produced more straw in relation to grain than did short wheats. The grain fractions ranged from 30 to 49% of the total dry matter, and the straw fractions ranged from 32 to 52% of the total dry matter.

By combine harvesting the whole plant (cutter-bar set just above ground level) and catching and discharge, up to 2.5 times more straw was recovered than with conventional combining, swathing, and baling. Baling only recovered from 1,900 to 2,400 kg/ha, or an average 15 to 17% of the total dry matter (22 to 45% of the "material other than grain" (MOG)). However, with baling, the remaining stubble residue (2,500 to 3,750 kg/ha) was available for erosion protection.

With whole-plant combining, from 55 to 70% of the MOG was recovered for potential energy conversion. Whole-plant combining increased the combine fuel energy and related time requirement up to 24%, depending upon the total dry matter levels as compared with conventional combining.

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